

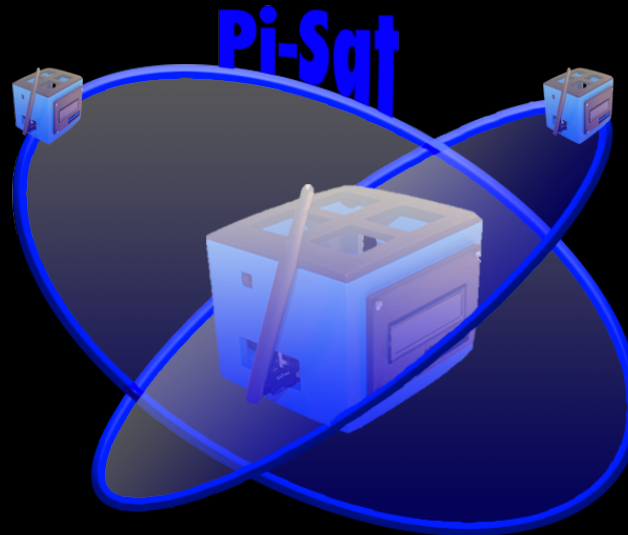
National Aeronautics and Space Administration



Pi-Sat:

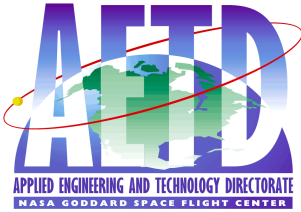
A Low Cost Small Satellite and Distributed Mission Test Platform

Alan Cudmore
Code 582



www.nasa.gov

NASA Goddard Space Flight Center *Software Engineering Division*



Outline



- Introduction:
 - What is the Pi-Sat?
 - Why Pi? Introduction to the Raspberry Pi
 - The sum is greater than the parts
 - Don't forget the Software.. The core Flight System
- Designs:
 - Pi-Sat Cube
 - Pi-Sat Wireless Node
 - Pumpkin Pi Card
- Applications:
 - Smallsat/Cubesat Prototype
 - Distributed Mission Ted Bed
 - Flight Software Training/Education
- Team
- Future Plans

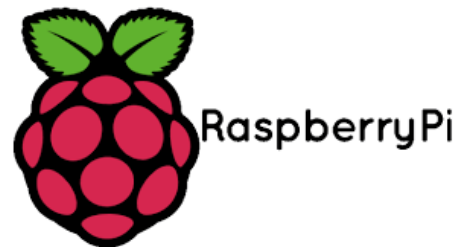
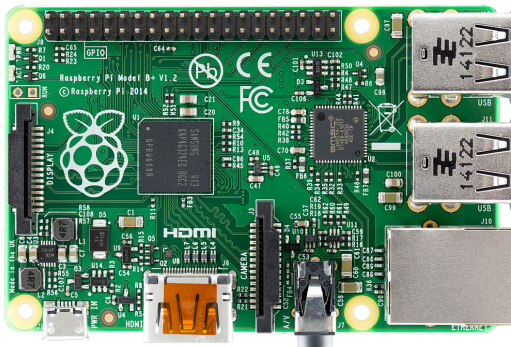
Introduction: What is the Pi-Sat?

- The Pi-Sat is a (**very!**) low cost platform for:
 - Prototyping Smallsat and Cubesat flight software
 - Research and development of Distributed Spacecraft Mission concepts
 - Flight software training and educational outreach
- The Pi-Sat combines:
 - A credit-card sized ARM processor (Raspberry Pi)
 - A suite of low cost sensors
 - A 3D printed enclosure and battery
 - NASA GSFCs core Flight System flight software architecture
- Funded by FY14 and FY15 IRADs



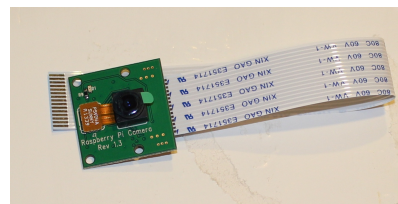
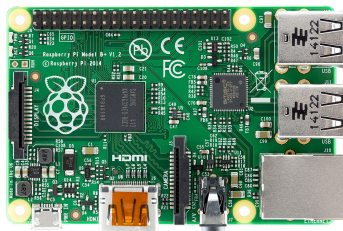
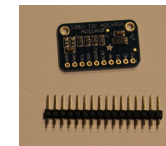
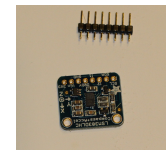
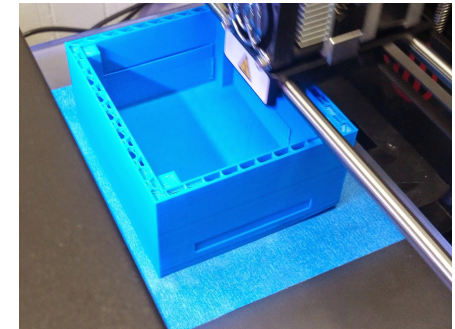
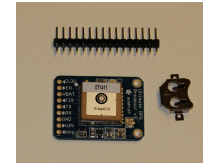
Introduction: Why Pi?

- The Pi-Sat is based on the \$35 **Raspberry Pi** single board computer
- Created by the Raspberry Pi Foundation in the UK
- Over 5 million have been sold to educators and hobbyists throughout the world
- Fits in with the “Maker” ecosystem of low cost, easy to use electronics
- The Raspberry Pi runs the Linux operating system, so it can run a wide variety of software, including GSFC Code 582s Core Flight System flight software architecture

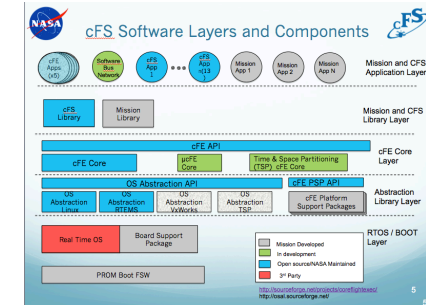


Introduction: The sum is greater than the parts

- The Pi-Sat is completed with:
 - A 3D Printed Enclosure – Designed and built by interns
 - An array of inexpensive sensors
 - GPS
 - Magnetometer-Compass/Accelerometer
 - High Definition Camera
 - A-to-D converter
 - Real Time clock
 - An SD card for program and data storage
 - Wi-Fi for network communication
 - Xbee Wireless for Peer-to-Peer mesh networking
 - An LCD or Touch Screen display
 - Custom Pi-Sat software
- **All for around \$325**

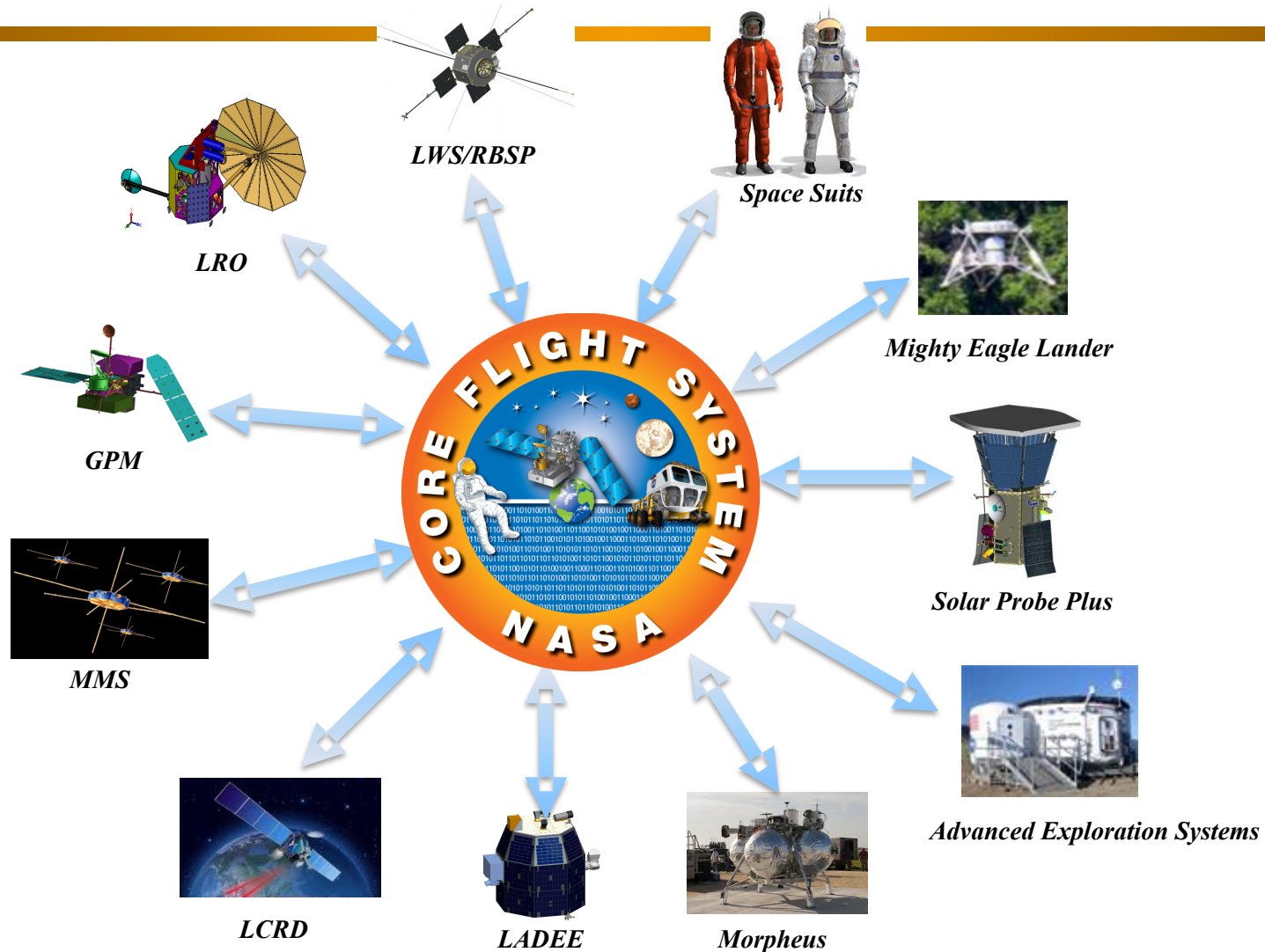


Introduction: Don't forget the Software.. The core Flight System



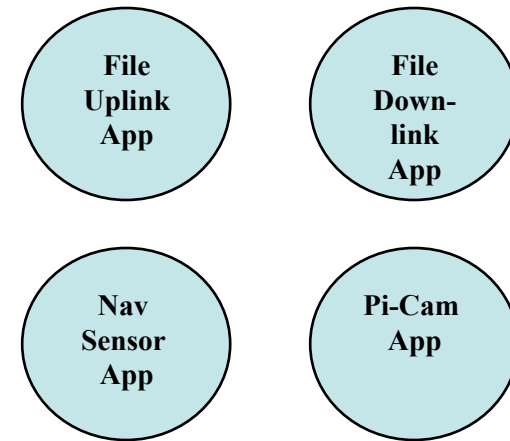
- The Pi-Sat Flight Software is NASA GSFCs **core Flight System** or **cFS**.
 - The cFS is a re-usable spacecraft flight software architecture and software suite that is both platform and project independent
 - The cFS is used on a number of missions throughout NASA (GPM, MMS, etc)
 - Although usually deployed on a real time operating system (RTOS) such as vxWorks, the cFS runs on Linux, and very well on the Pi.
 - The Pi is powerful enough to not only run the cFS, but it can serve as a development system and mini ground system!
 - More info: <http://cfs.gsfc.nasa.gov>
- The core Flight System is Open Source, so it is available to anyone to use on a Raspberry Pi based system

Introduction: cFS use at NASA



Introduction: Don't forget the Software.. Custom Pi-Sat Software

- In addition to the cFS, the following Custom Pi-Sat software was developed
 - cFS Applications
 - File Uplink cFS App
 - File Downlink cFS App
 - Nav Sensor cFS App
 - Pi-Cam cFS App
 - Custom Pi-Sat LCD and Touchscreen Menu Systems
 - Startup/Shutdown Scripts
 - Python/QT4 and ZeroMQ based simple ground system (Runs on the Raspberry PI)



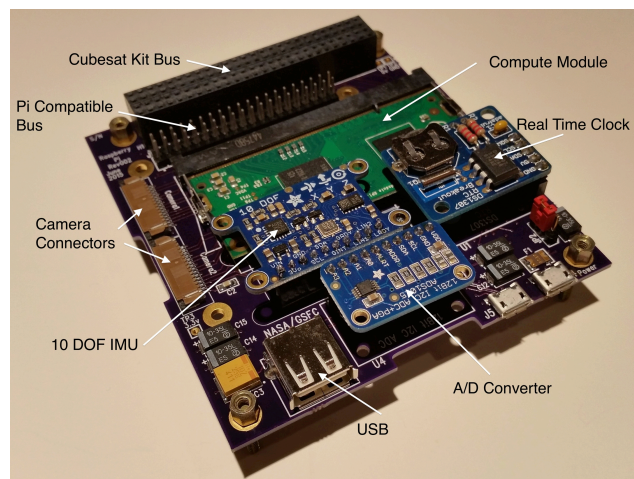
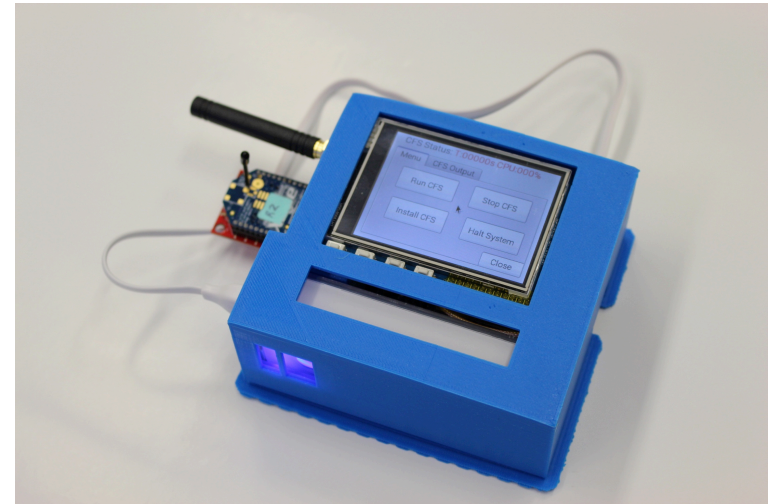
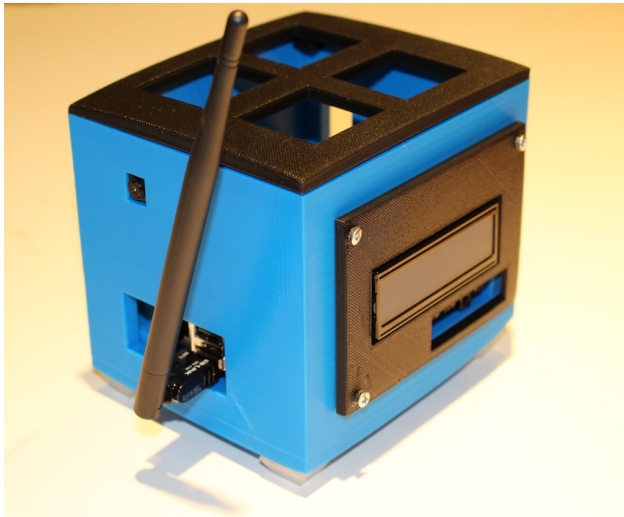
Command System Main Page

cFE/CFE Subsystem Commands

Available Pages Close

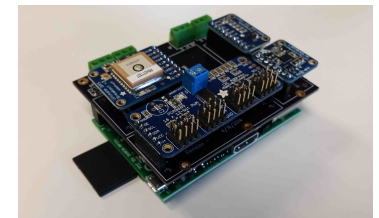
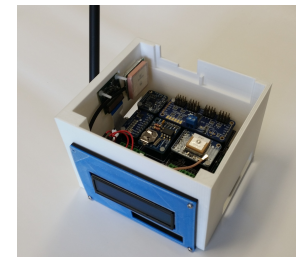
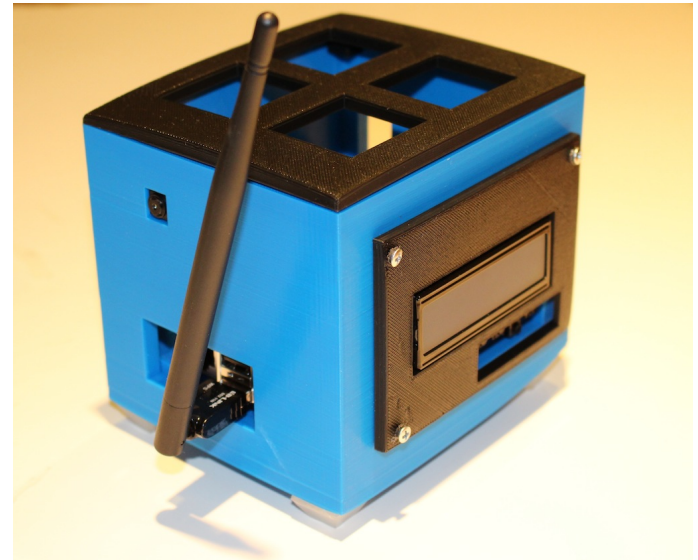
Subsystem/Page	Packet ID	Send To		
Executive Services (CPU1)	0x1806	127.0.0.1	Display Page	ES No-Op
Software Bus (CPU1)	0x1803	127.0.0.1	Display Page	
Table Services (CPU1)	0x1804	127.0.0.1	Display Page	
Time Services (CPU1)	0x1805	127.0.0.1	Display Page	Time No-Op
Event Services (CPU1)	0x1801	127.0.0.1	Display Page	
Command Ingest LAB	0x1884	127.0.0.1	Display Page	
Telemetry Output LAB	0x1880	127.0.0.1	Display Page	Enable Tlm
Spectrometer App	0x1850	127.0.0.1	Display Page	

Pi-Sat Designs



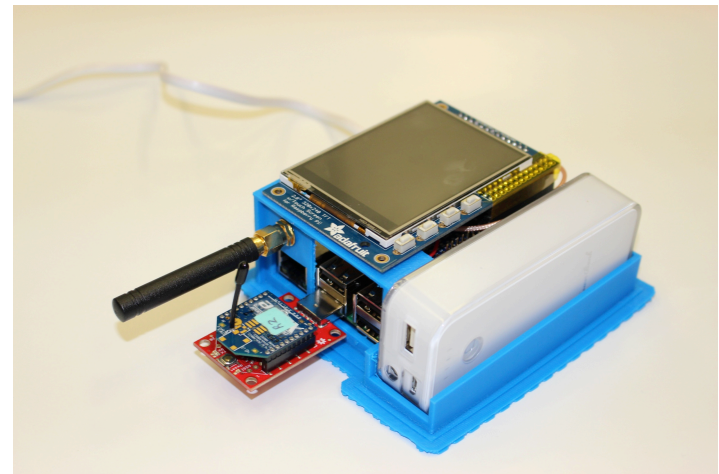
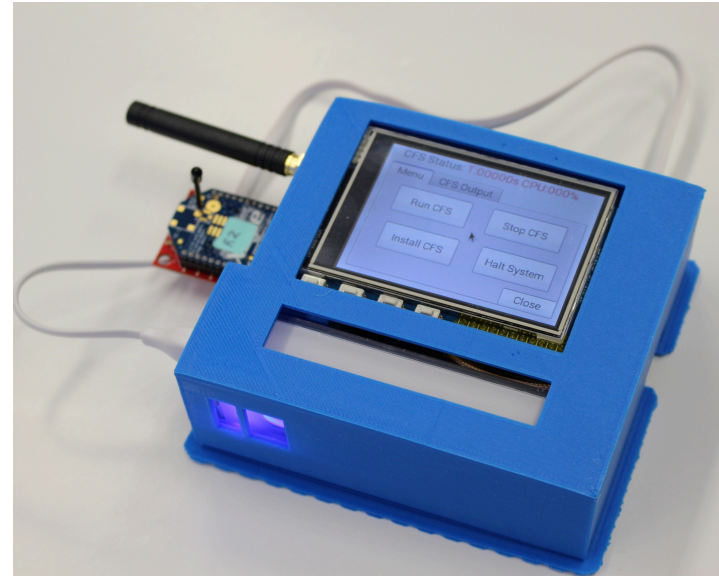
Pi-Sat Designs: Pi-Sat Cube

- The Pi-Sat Cube is a 1U (OK.. 1.2U) sized Cubesat prototype
- CPU: Raspberry Pi Model B
- Sensors:
 - GPS
 - Mag/Compass/Accelerometer
 - Raspberry Pi Camera
 - A/D Converter
 - PWM control board
 - LCD interface
- Wi-Fi network
- Power
 - USB or 4400mAH battery



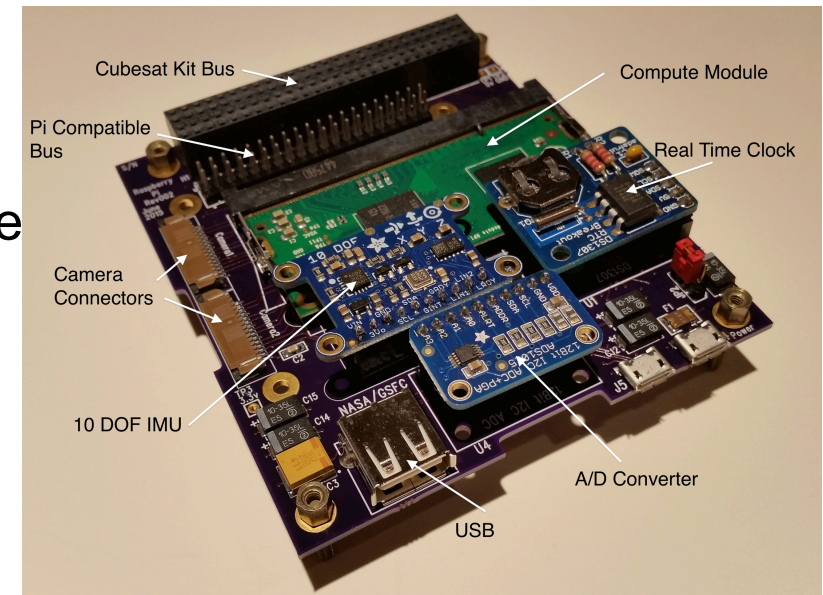
Pi-Sat Designs: Pi-Sat Wireless Node

- The Pi-Sat Wireless node is more compact model for testing wireless mesh networks with the cFS flight software
- CPU: Raspberry Pi 2 B+ (Quad Core)
- Sensors:
 - GPS
 - Mag/Compass/Accelerometer (10 DOF IMU)
 - Touch Screen interface
- Wi-Fi network
- Xbee Mesh wireless for Peer-to-Peer comm
- Power
 - USB or 4400mAH battery



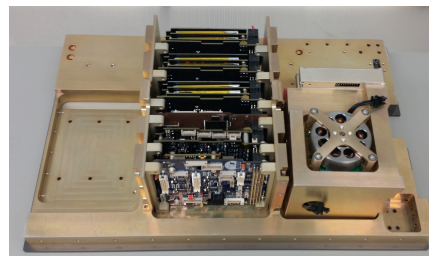
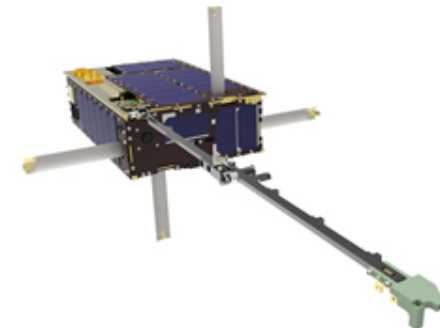
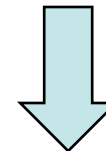
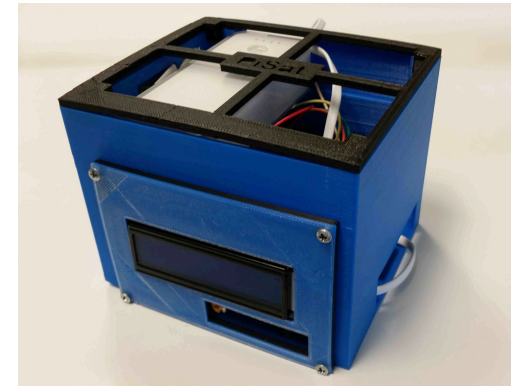
Pi-Sat Designs: Pumpkin Pi Card

- The Pumpkin Pi Card is a 1U Cubesat processor card (prototype) based on the Pumpkin Cubesat kit bus
- CPU: Raspberry Pi Compute Module, upgradeable to the Raspberry Pi 2 Compute Module when released
- Sensors:
 - 10 DOF IMU unit
 - Real Time Clock
 - A/D Converter
 - Raspberry Pi Camera Connectors
- Network interface through USB port
- Power through mini-USB or Cubesat Bus Connector



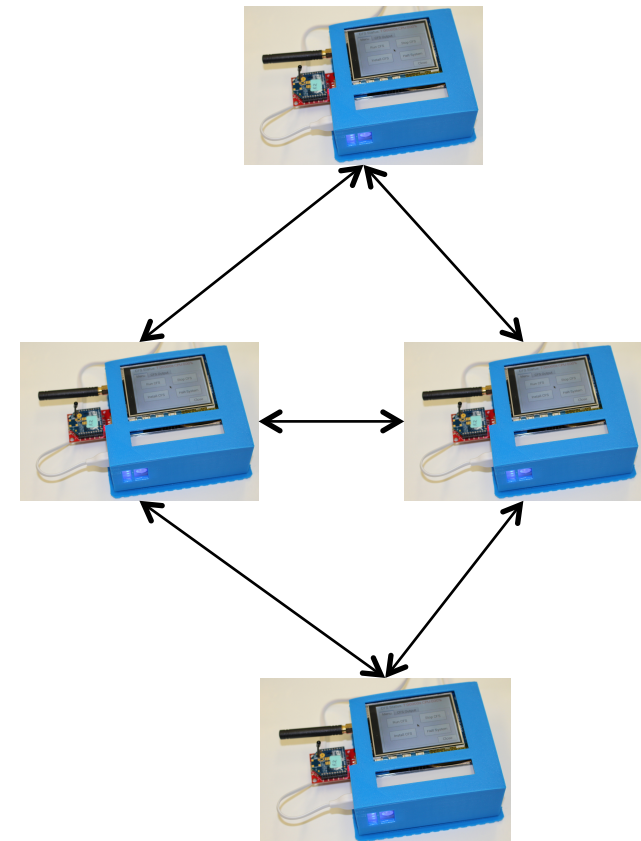
Applications of the Pi-Sat: Smallsat/Cubesat Prototype

- The Pi-Sat platform can be used to rapidly prototype cFS flight software for Cubesat Missions.
- Realistic sensors for Navigation and Control
- I2C, SPI, GPIO, Ethernet, and USB for instrument interfaces
- “Out of the Box” cFS flight software with a simple ready to use ground system for initial setup
- Pumpkin Pi model is more realistic and gets closer to integrating into a real Cubesat stack.



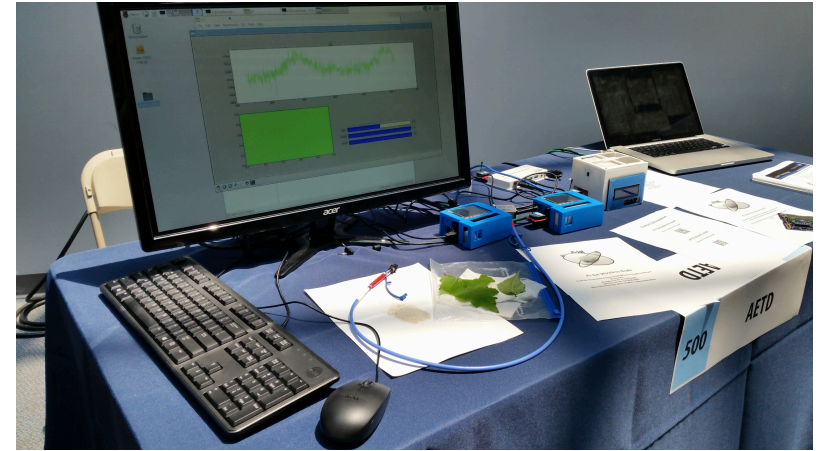
Applications of the Pi-Sat: Distributed Spacecraft Mission Test Bed

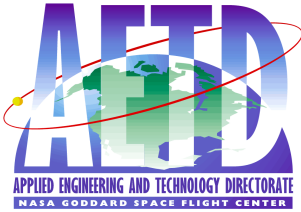
- The Pi-Sat platform can also be used for a Distributed Spacecraft Mission (DSM) Test Bed
- Xbee Mesh Network cFS extension allows the cFS “Software Bus” to communicate among multiple spacecraft units
- Low cost platform to develop Peer-to-peer cFS communication protocols and ground system concepts for constellations



Applications of the Pi-Sat: Flight Software Training / Education

- The Pi-Sat platform has been an excellent opportunity for hands-on flight software training for 582 Interns and Pathways students.
- Most of the 3D design, custom cFS Applications, and Ground System software has been developed by the Interns/Pathways students.
 - Keegan Moore integrated an ocean spectrometer instrument into Pi-Sat/ cFS software
- Working with real hardware gives students a sense of what Flight Software (and hardware) development is about.





Pi-Sat Team



-
- **Michael Lin / 561**
 - Pi-Sat Cube Sensor Card Design and Pumpkin Pi Card Design
 - **Jose Martinez Pedraza / 582 / Pathways**
 - cFS App development
 - Ground System Development
 - 3D Enclosure Design
 - Hardware/Software Integration
 - **Keegan Moore / 582 – Capitol Tech / Summer Intern**
 - cFS App development
 - 3D Enclosure Design
 - Hardware/Software Integration
 - **Alan Cudmore / 582**
 - IRAD PI and Pi-Sat lead (Pi-PI?)
 - (Michael Cudmore – Pi-Sat logo design)
-

What's Next?

- FY15 IRAD Wrap up
 - Delivery of Wireless Nodes
 - Documentation and Design wrap up
- FY16 Collaboration with Planetary Systems Lab
 - Continue Collaboration with ocean spectrometer instruments and Cubesat / cFS prototypes
- Consolidation of hardware designs
 - Sensor Pi-HAT card that plugs into Raspberry Pi or Pumpkin Pi
 - Unified flight software
- Education opportunities?
 - Collaboration with Capitol Technology University?
 - Kit for educators?

